

# Multi-Functional Composites for Space Travel: Design Considerations and Early Concepts Using Reduced Graphene Oxide as a Polymer Reinforcement



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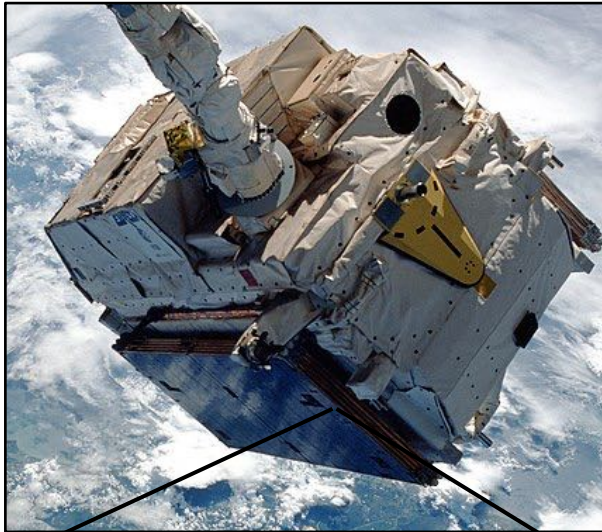
NASA Exploration Science Forum

Georgia Institute of Technology, Atlanta, GA

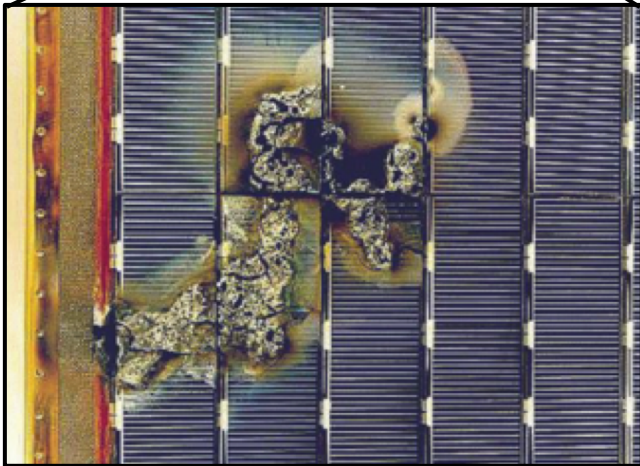
Jul. 25<sup>th</sup>, 2019



# Risk Factors of Space: Static Charging



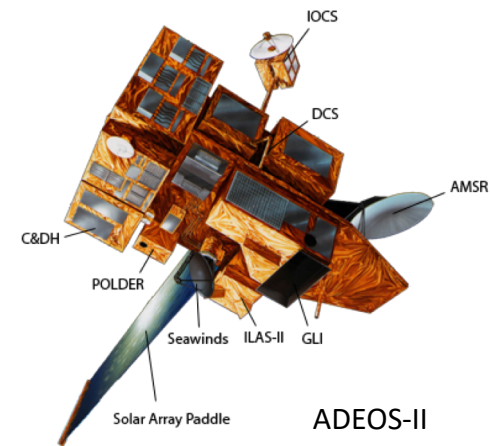
EURECA STS-57



- Examples:
  - Galaxy 15 – telecommunications satellite – **1 year delay**
  - Advanced Earth Observing Satellite 2 (ADEOS-II) - **destroyed**
  - EURECA STS-57 – **Solar cell damage**
- Effects:
  - Electric shock
  - Instrument error
  - Equipment failure

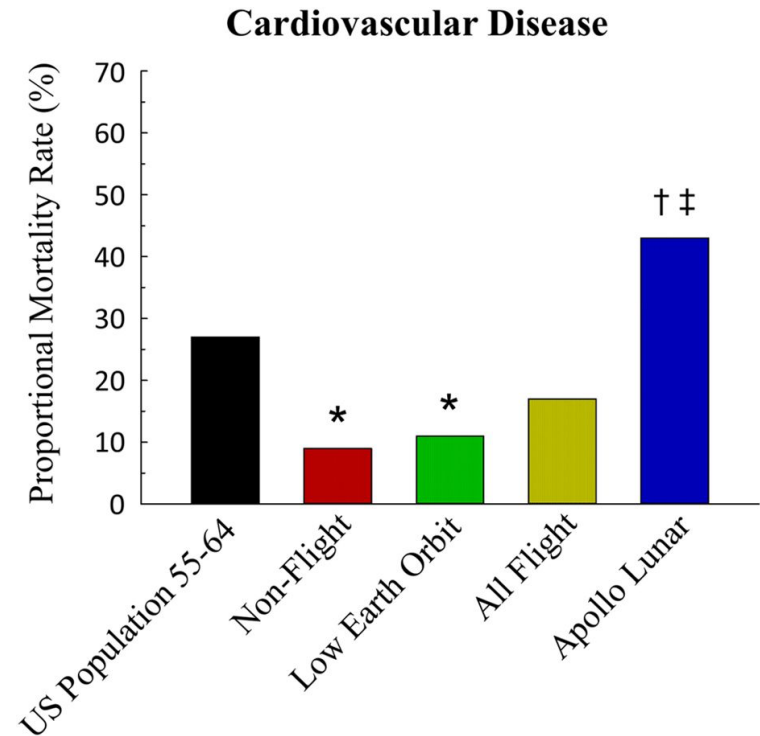
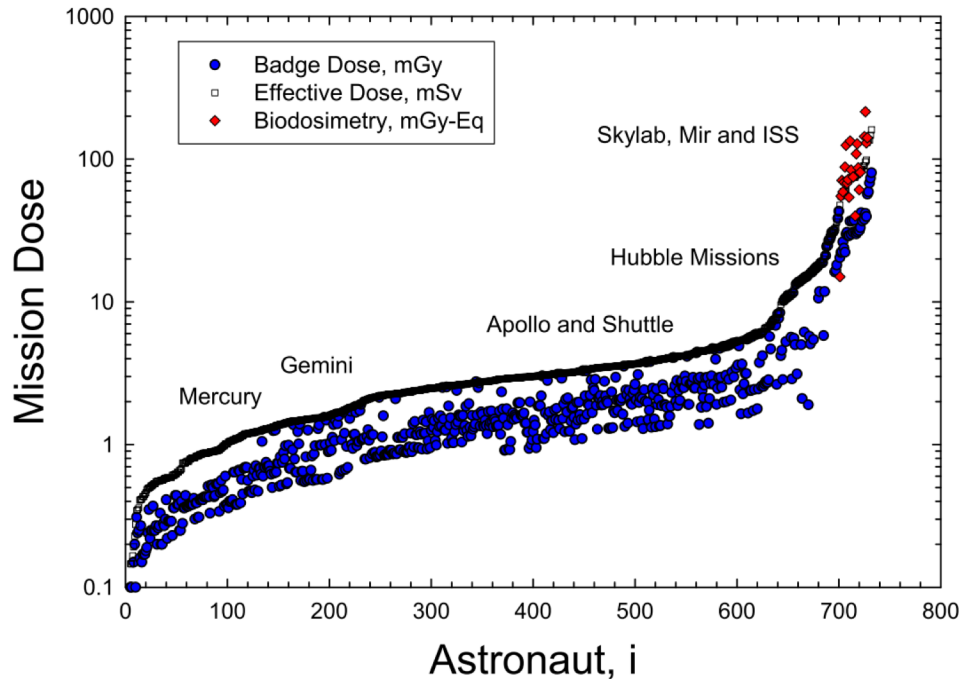


Commercial anti-static coatings  $\approx 100 \text{ M}\Omega$



ADEOS-II

# Health Hazards of Radiation Exposure

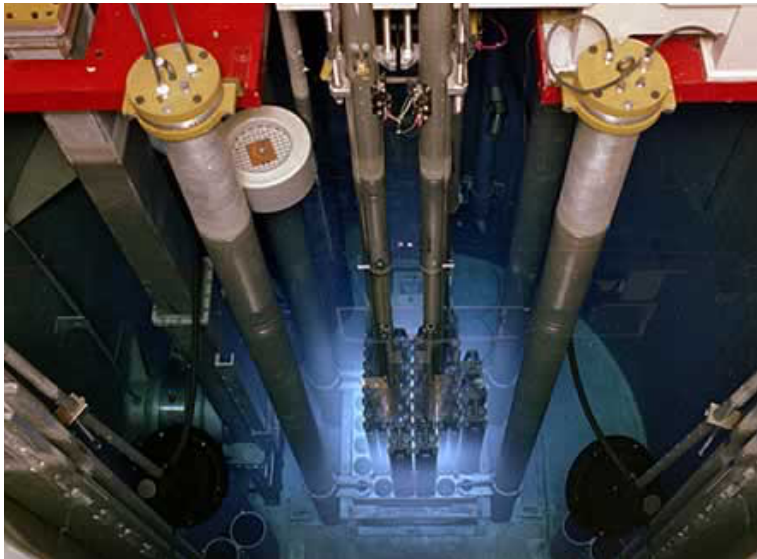


Radiation exposure is inevitable in space environments, but the goal should be to keep doses **as low as reasonably achievable!**

# Radiation Attenuation

## 1) Absorb radiation

- Radiation-induced radical formation
- Quench or stabilize through resonance
- Short-term approach
- Heavy metals, polysulfones



Wiki Commons

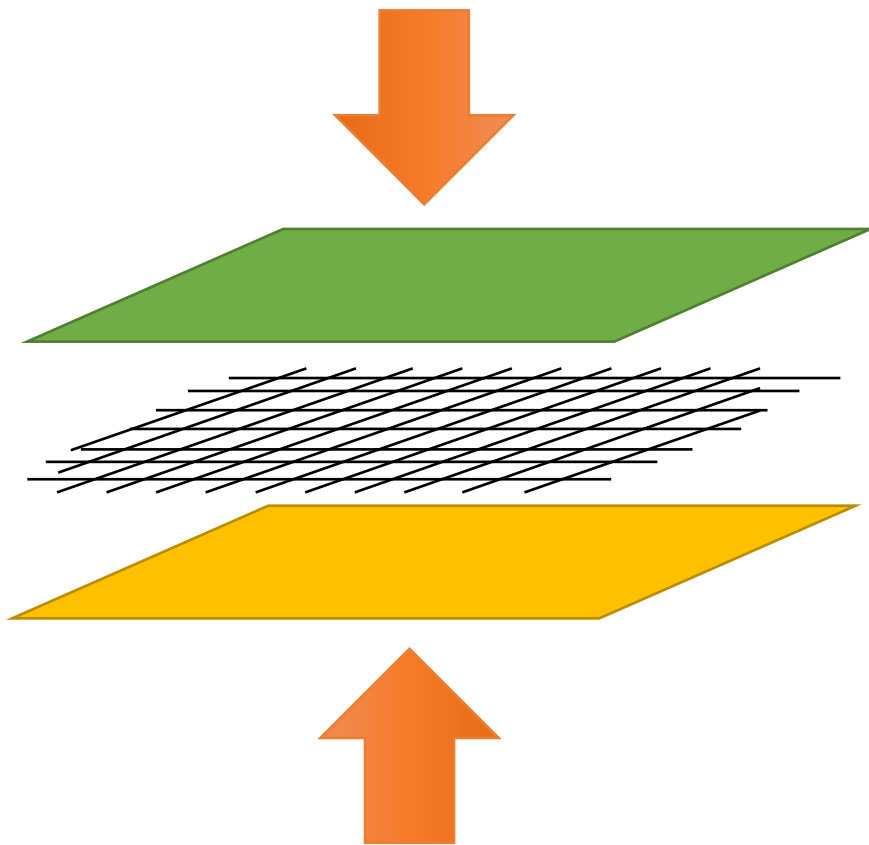


## 2) Maximize H content

- Best at slowing particle-based radiation
- Limit degradation through robust chemistry
- Best long-term approach
- Water, LH2



# Ultimate Goal – Multilayer Composite



## 1) Conductive Layer

- Dissipate static charge
- Impact resistance
- UV resistance
- Radiation attenuation

## 2) Fiber Reinforcement

- Mechanical Properties
- Survive Radiation

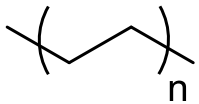
## 3) Radiation Attenuation Layer

- Maximize Radiation attenuation

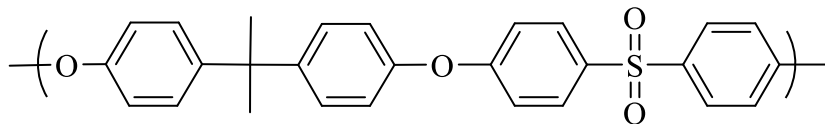
# Realizing Conductive Radiation Shielding Materials

## Thermoplastics

- Scalable chemistry
- Range of performance tunability
- Radiation attenuators
- Versatile fabrication
- **Not generally conductive**



**Polyethylene**



**Polysulfone**

## Graphene

- Simple chemistry
- High conductivity
- Excellent mechanical properties
- **Not readily miscible**



Reduced graphene oxide

# Melt Compounding HDPE-rGO Composites

Batch size  $\approx 5.5$  g  
Mix: 190 °C and 200 rpm

**Approach:** Synthesize chemically modified reduced graphene oxides to enhance miscibility in a polyethylene matrix to confer electrical conductivity and enhanced mechanical properties.

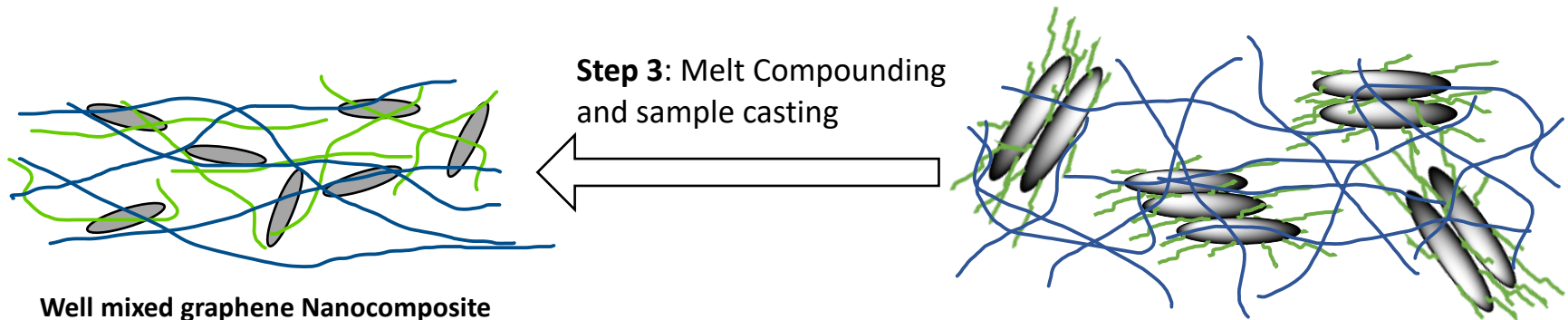
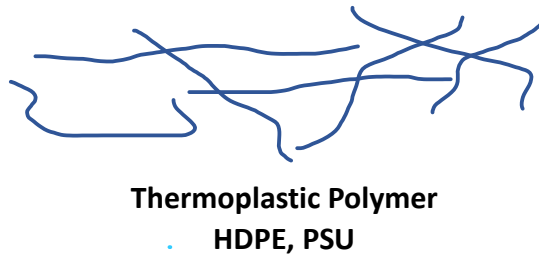
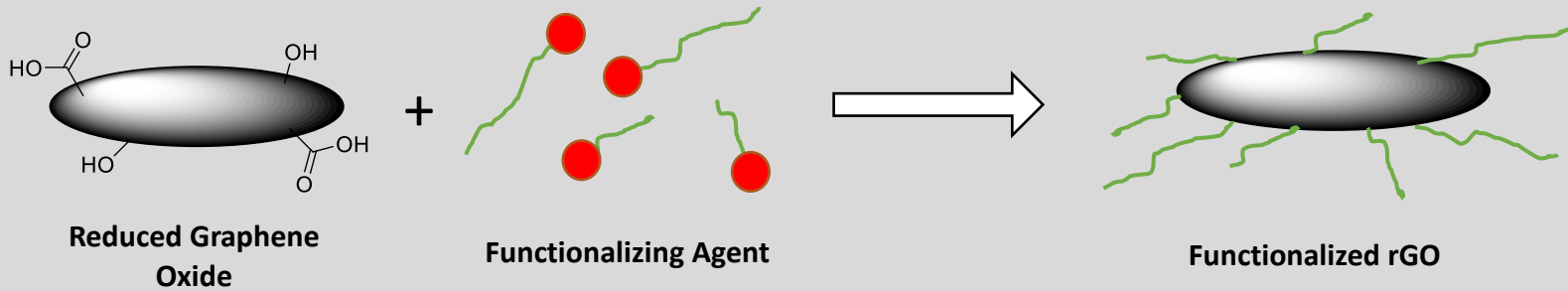
Unmodified rGO after melt pressing at 0.1% by wt. in HDPE

7.5 cm

Neat HDPE 0.1% rGO

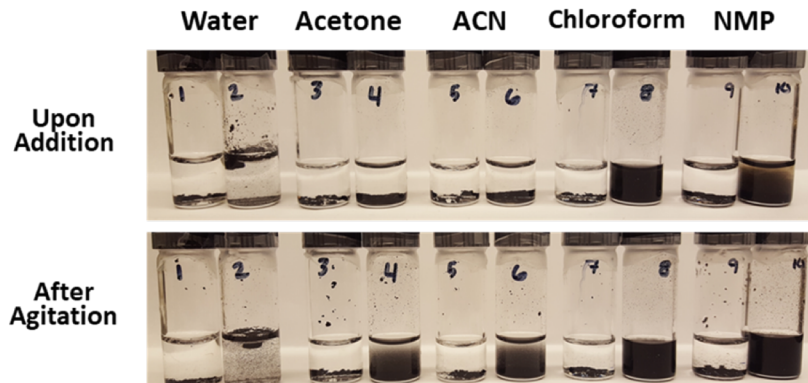
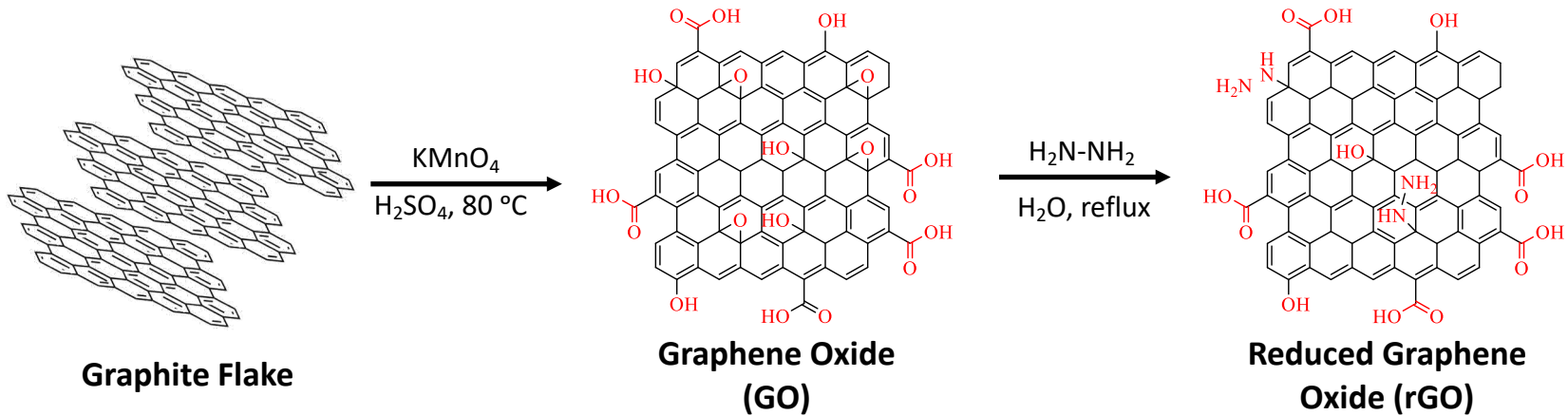
15 cm

# Composite Formation Process





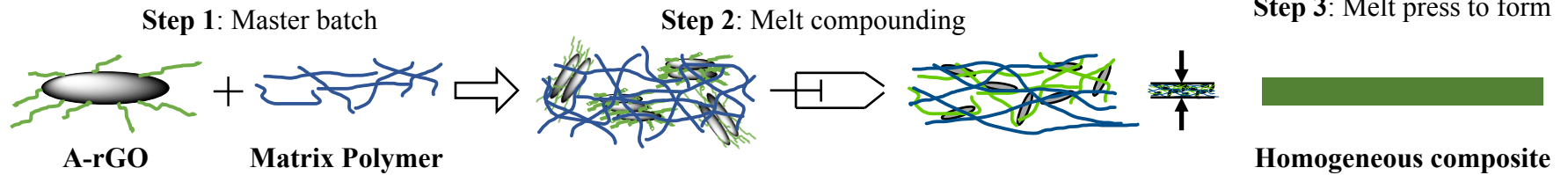
# Graphene Oxide Synthesis



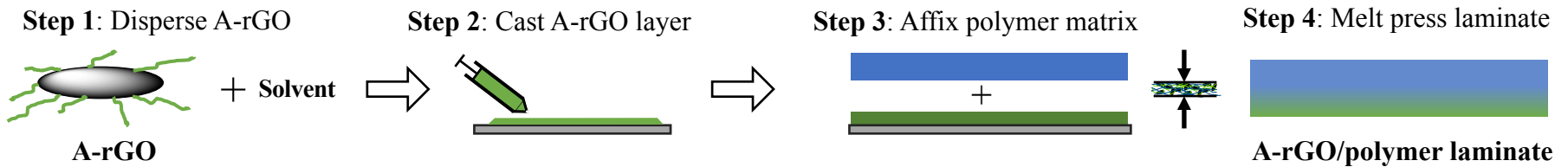
Material	t [mm]	$\rho$ [ $\Omega\cdot\text{m}$ ]	$\sigma$ [ $\text{S cm}^{-1}$ ]
Graphite Flake	0.20	$3.4 \times 10^{-6}$	2940
rGO	0.14	$1.3 \times 10^{-5}$	750
A-rGO	0.17	$3.0 \times 10^{-5}$	340

# Melt Processing Strategies

## A) Melt Compounding

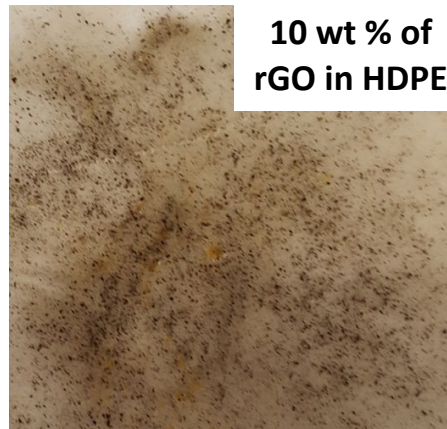
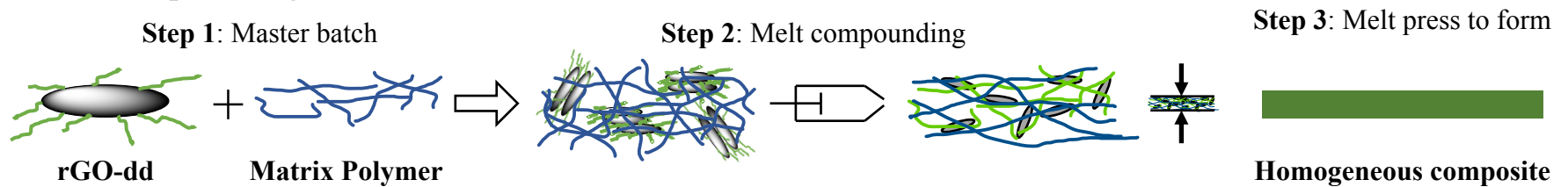


## B) Melt Lamination

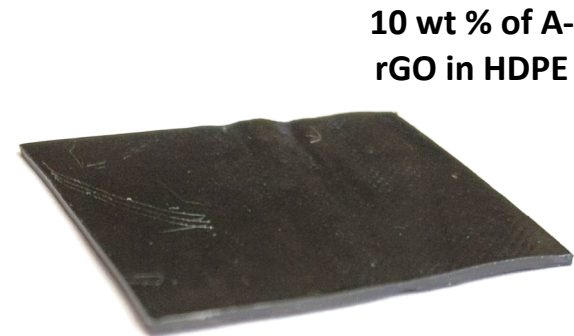


# Melt Compounding

## Melt Compounding

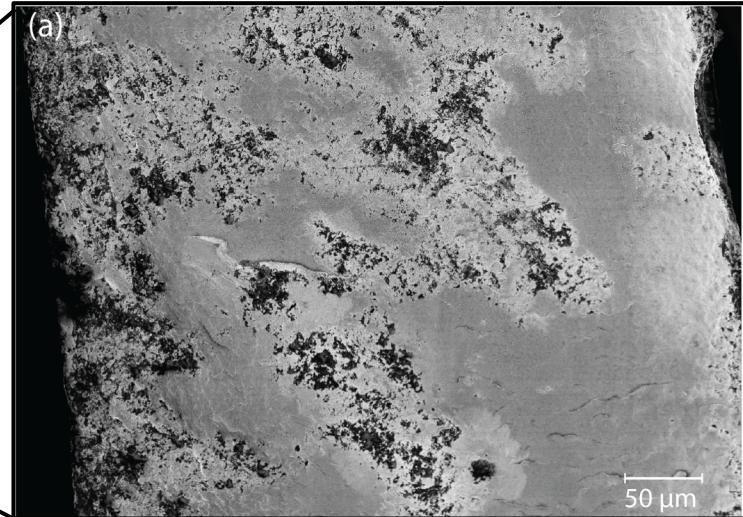
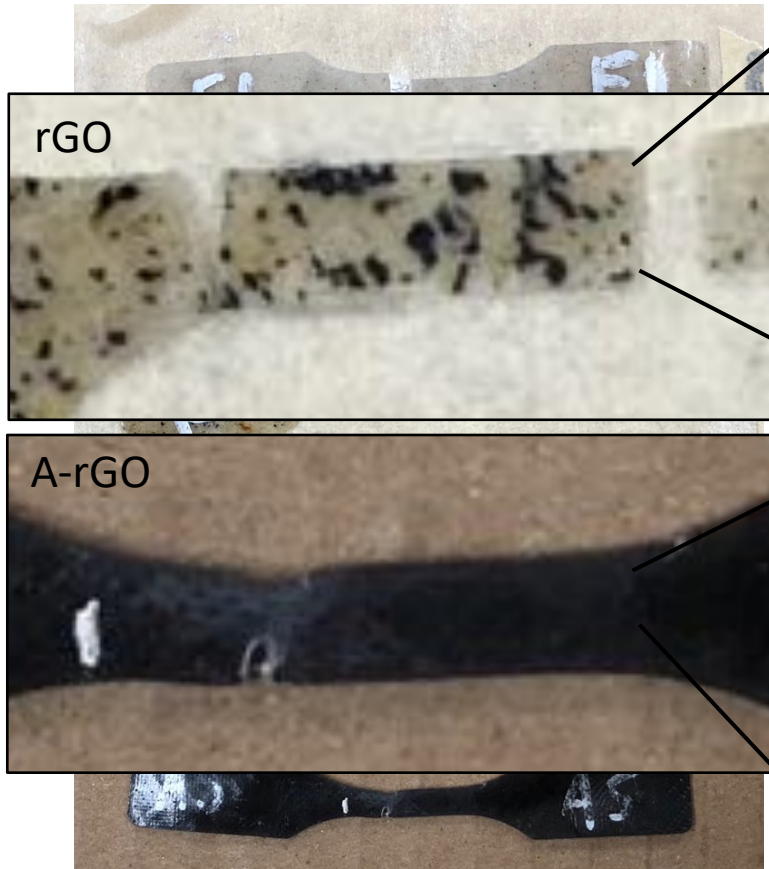


Not Conductive



$R_s \approx 10 \text{ M}\Omega$

# Qualitative Assessment of Miscibility Enhancement

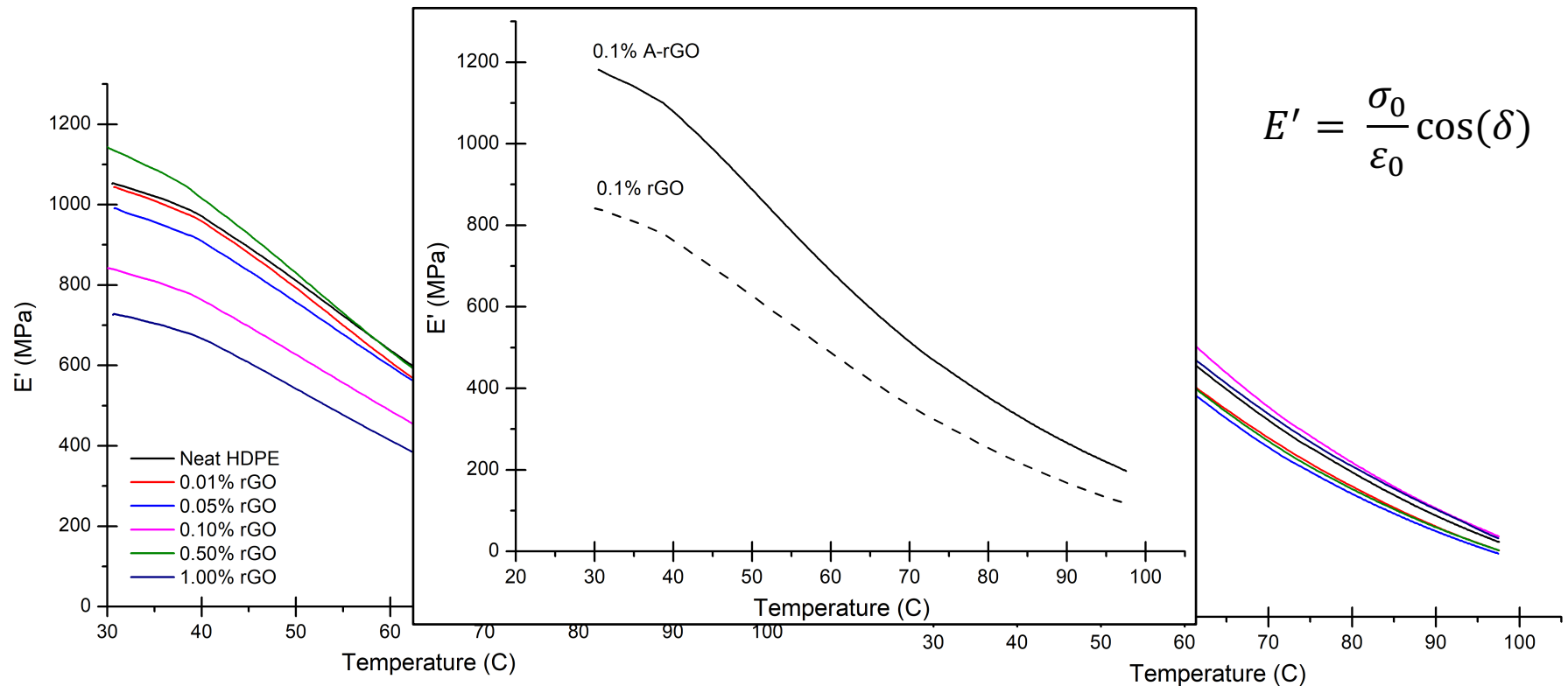


Valeria Saponara, UC Davis



# DMA Thermal Sweep – Storage Modulus

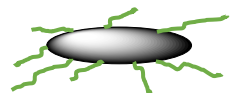
Ability to store or return energy, the “solid” component of material’s behavior.



# Melt Lamination

## Melt Lamination

Step 1: Disperse A-rGO



rGO-dd

+ Solvent



Step 2: Cast A-rGO layer



Step 3: Affix polymer matrix



Step 4: Melt press laminate



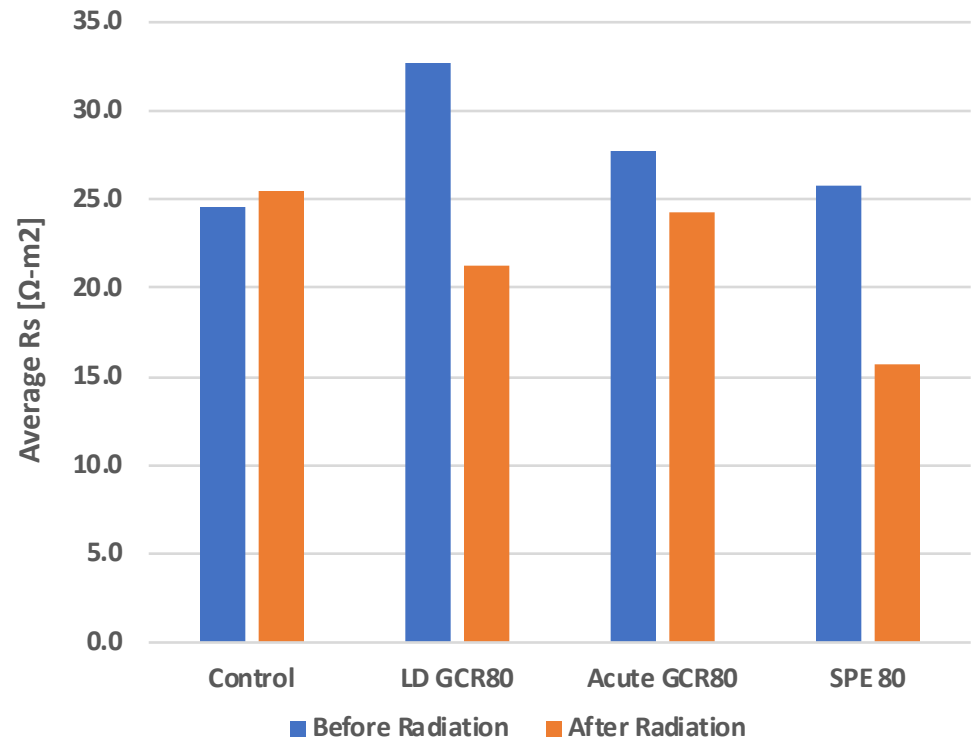
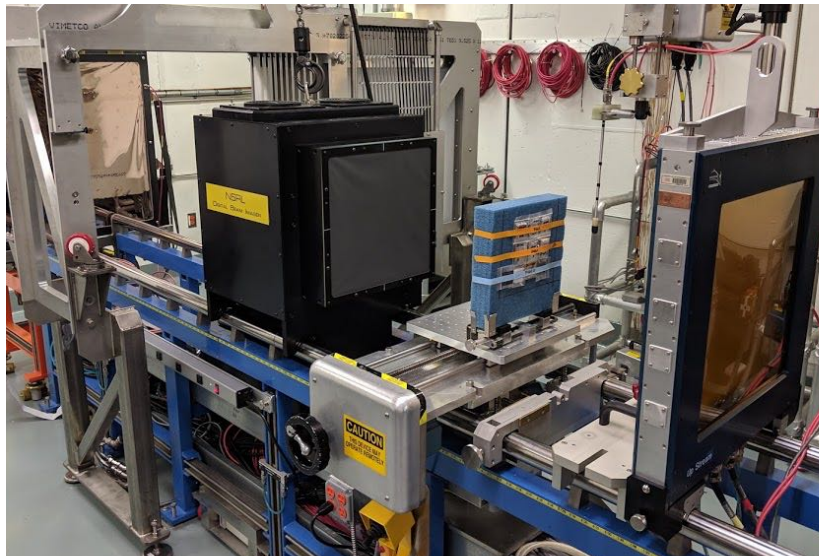
A-rGO/polymer laminate



Material	t [mm]	$\rho$ [ $\Omega$ -m]	$\sigma$ [S cm <sup>-1</sup> ]
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rGO	0.14	$1.3 \times 10^{-5}$	750
A-rGO	0.17	$3.0 \times 10^{-5}$	340
Laminate	--	$2.6 \times 10^1$	

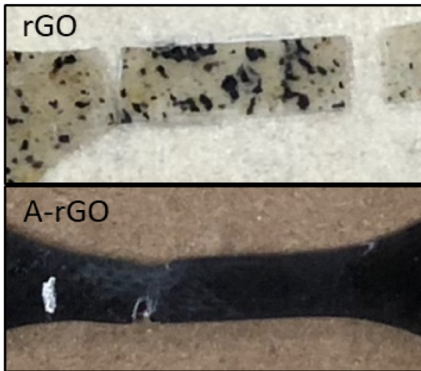
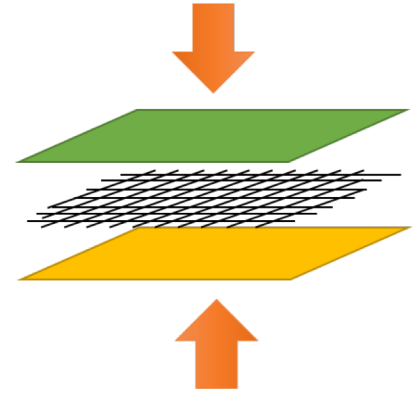
# Simulating Space Radiation at NSRL

- Galactic Cosmic Ray at low and acute dose rates to 80 cGy
- Solar Particle Event 80 cGy



# Conclusions & Future Plans

- Multilayer concept that inspired new synthetic modification strategy to increase the miscibility and processability of rGOs



- Demonstrated differences in composite homogeneity using different fabrication schemes
- A-rGO exhibits tolerance to simulated space radiation.

- Continuing to learn about the effects of radiation exposure exploring fiber-reinforced composites





# Acknowledgements

- NASA Solar System Exploration Research Virtual Institute: agreement NNA17BF68A.
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